DEVELOPMENT OF A NETWORK DATA ENVELOPMENT ANALYSIS (DEA) MODEL TO MEASURE THE PERFORMANCE OF THE PRODUCTION LINE

NOR AFFAF BINTI MOHD ZAINAL ABIDDIN

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

_____

(Supervisor's Signature)

Full Name : TS. DR. MUHAMAD ARIFPIN BIN MANSOR

Position : ASSOCIATE PROFESSOR

Date : 14 MARCH 2020

_____

(Co-supervisor's Signature)

Full Name : DR. SITI NADIAH BINTI MOHD SAFFE

Position : SENIOR LECTURER

Date : 14 MARCH 2020

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

(Student's Signature)

Full Name : NOR AFFAF BINTI MOHD ZAINAL ABIDDIN

ID Number : MMF15016

Date : 14 MARCH 2020

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NOR AFFAF BINTI MOHD ZAINAL ABIDDIN

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ABSTRAK

Barisan pengeluaran dalam industri pembuatan biasanya terdiri daripada beberapa proses dan mesti melalui pengukuran prestasi untuk menentukan sama ada ia cekap atau tidak cekap. Salah satu kaedah yang digunakan secara meluas untuk pengukuran prestasi oleh organisasi adalah *Data Envelopment Analysis* (DEA). DEA adalah teknik bukan parametrik yang digunakan untuk mengukur kecekapan *Decision Making Units* (DMUs) yang menggunakan *input* untuk menghasilkan *output* yang lazim, sementara DMU merujuk kepada entiti yang akan diukur oleh DEA. DEA dianggap sebagai salah satu teknik paling banyak digunakan untuk mengukur prestasi DMU. Walau bagaimanapun, organisasi tidak boleh menggunakan model DEA tradisional untuk mendapatkan skor kecekapan untuk barisan pengeluaran dalaman kerana model ini tidak dapat mengukur bahagian dalam barisan pengeluaran dan tidak mengambil kira hubungan antara setiap proses. Oleh itu, DEA Rangkaian boleh digunakan untuk mengukur prestasi barisan pengeluaran secara terperinci dengan mengukur proses di dalam barisan pengeluaran juga. Organisasi perlu mempertimbangkan hubungan antara setiap proses kerana apabila beberapa proses tidak berfungsi dengan cekap, maka itu akan mempengaruhi kecekapan seluruh proses juga. Objektif penyelidikan ini adalah untuk membangunkan model DEA Rangkaian berdasarkan garis pengeluaran sebenar dan untuk mendapatkan skor kecekapan dari model DEA Rangkaian yang dibangunkan. Kajian ini bermula dengan mengkaji semula penyelidikan sebelumnya untuk mempelajari teknik DEA dan data yang diperlukan. Kemudian, data terdiri daripada input yang digunakan dan output yang dihasilkan oleh setiap *Sub* DMU dikumpulkan untuk dilaksanakan semasa pembangunan model rangkaian dan pengiraan kecekapan. Semasa penyelidikan ini, rangka kerja membangunkan model DEA Rangkaian telah diwujudkan sebagai garis panduan bagi para penyelidik atau syarikat untuk membangunkan model rangkaian berdasarkan pada barisan pengeluaran mereka sendiri. Model rangkaian dibangunkan dalam penyelidikan ini dan mereka mencerminkan garis produksi yang sebenarnya dan juga menunjukkan hubungan setiap sub DMU diukur secara terperinci. Model rangkaian ini juga bertindak sebagai pengesahan kepada kerangka mengakui bahwa model-model yang dibangunkan dalam penyelidikan ini atau yang akan dikembangkan pada masa akan datang menggunakan kerangka ini dapat menjadi representasi yang dapat dilalui dalam jalur produksi di dunia nyata. Setelah model itu dibangunkan, pengiraan kecekapan dilakukan dengan menggunakan perisian yang dinamakan MaxDEA dan hasil yang diperolehi dipaparkan di dalam jadual. Antara kesemua lima DMU, DMU 2 dan DMU 3 ditunjukkan dengan cekap dengan skor kecekapan keseluruhan 1 dan DMU 1 ditunjukkan sebagai yang paling tidak cekap dengan skor kecekapan keseluruhan terendah 0.988602. Walaupun DMU 1, DMU 4 dan DMU 5 tidak cekap, skor kecekapan masing-masing adalah hampir sama dengan 1. Kesimpulannya, model DEA Rangkaian telah dibangunkan berdasarkan garis produksi sebenar di salah satu syarikat di Malaysia. Skor kecekapan model DEA Rangkaian yang dibangunkan juga diperoleh menggunakan model rangkaian yang dibangunkan. Bagi sumbangan, model DEA Rangkaian boleh dibangunkan oleh syarikat berdasarkan garis produksi sebenar mereka untuk mengukur barisan pengeluaran dalaman dan untuk mengesan di mana ketidakcekapan mungkin berlaku semasa pengeluaran. Dengan kata lain, ia boleh membantu syarikat-syarikat untuk berusaha untuk pembaikan berterusan hanya jika perlu.

ABSTRACT

The production line in manufacturing industry usually consists of several processes and must go through performance measurement to determine whether they are efficient or inefficient. One of the methods widely used for performance measurement by the organizations is the Data Envelopment Analysis (DEA). Data Envelopment Analysis (DEA) is a non-parametric technique used to measure the efficiency of the Decision Making Units (DMUs) which use common inputs to produce common outputs, while DMU refers to the entity that is going to be measured by the DEA. The DEA is considered to be one of the most widely used techniques to measure the performance of the DMUs. However, the organizations cannot use the traditional DEA model to obtain the efficiency scores for internal production line because this model cannot measure the inside of the production line and does not take into account the relationship between each process. Thus, the Network DEA can be used to measure the performance of the production line in details by measuring the processes in the production line as well. The organizations need to consider the relationship between each of the process because when some of the processes do not perform efficiently, then it might affect the efficiency of the entire processes as well. The objectives of this research are to develop the Network DEA model based on the actual production line and to obtain the efficiency scores from the Network DEA model developed. This research begins by reviewing previous researches to study the DEA techniques and the data required. Then, the data consist of the inputs consumed and the outputs produced by each sub DMUs was collected to be implemented during the network model development and the efficiency calculation. During this research, the framework of developing the Network DEA model was created as a guideline for the researchers or the companies to develop the network model based on their own production line. The network model was developed in this research and they reflected the actual production line and also show the relationship of each sub DMUs measured in details. This network model also acts as a validation to the framework acknowledge that the models developed in this research or that are going to be developed in the future using this framework can be a passable representation of the production line in the real world. Once the model was developed, the calculations of the efficiency were done by using the software called MaxDEA and the results obtained were displayed in table. Among all five DMUs, DMU 2 and DMU 3 were shown to be efficient with the overall efficiency scores of 1 and DMU 1 was shown to be the most inefficient with the lowest overall efficiency scores of 0.988602. Although DMU 1, DMU 4 and DMU 5 were inefficient, the total efficiency scores for each of them were approximately close to 1. In conclusion, a Network DEA model was developed based on the actual production line in one of the companies in Malaysia. The efficiency scores of the Network DEA model developed was also obtained using the network model developed. As for contributions, the Network DEA model can be developed by companies based on their actual production line to measure the internal production line and to detect where the inefficiency might occur during the production. In other words, it can help companies to strive for continuous improvement only where necessary.

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LIST OF SYMBOLS

ε	Small non-Archimedean number
λ	Relative weight
θ	Efficiency
$\emptyset$	Unique Value Function

LIST OF ABBREVIATIONS

DEA	Data Envelopment Analysis
DMU	Decision Making Unit
TOPSIS	Technique for Order Preference by Similarity to Find an Ideal Solution

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REFERENCES

Adler, N., Liebert, V., & Yazhemsky, E. (2013). Benchmarking airports from a managerial perspective. Omega, 41(2), 442–458. https://doi.org/10.1016/J.OMEGA.2012.02.004

Avkiran, N. K., & McCrystal, A. (2012). Sensitivity analysis of network DEA: NSBM versus NRAM. Applied Mathematics and Computation, 218(22), 11226–11239. https://doi.org/10.1016/J.AMC.2012.05.014

Badiezadeh, T., Saen, R. F., & Samavati, T. (2017). PT. Computers and Operations Research. https://doi.org/10.1016/j.cor.2017.06.003

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. Management Science, 30(9), 1078–1092. https://doi.org/10.1287/mnsc.30.9.1078

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. Econometrica, 50(6), 1393. https://doi.org/10.2307/1913388

Charnes, A., & Cooper, W. W. (1984). The non-archimedean CCR ratio for efficiency analysis: A rejoinder to Boyd and Färe. European Journal of Operational Research, 15(3), 333–334. https://doi.org/10.1016/0377-2217(84)90102-4

Charnes, A., Cooper, W. W., Golany, B., Halek, R., Klopp, G., Schmitz, E., & Thomas, D. (1986). Two phase data envelopment analysis approaches to policy evaluation and management of army recruiting activities: Tradeoffs between joint services and army advertising. Center for Cybernetic Studies. University of Texas-Austin Austin, Tex, USA.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Chen, C. M. (2009). A network-DEA model with new efficiency measures to incorporate the dynamic effect in production networks. European Journal of Operational Research, 194(3), 687–699. https://doi.org/10.1016/j.ejor.2007.12.025

Chen, C., & Yan, H. (2011). Network DEA model for supply chain performance evaluation. European Journal of Operational Research, 213(1), 147–155. https://doi.org/10.1016/j.ejor.2011.03.010

Cook, W. D., & Green, R. H. (2004). Multicomponent efficiency measurement and core business identification in multiplant firms: A DEA model. European Journal of Operational Research, 157(3), 540–551. https://doi.org/10.1016/S0377-2217(03)00298-4

Cruz, N. F. da, Carvalho, P., & Marques, R. C. (2013). Disentangling the cost efficiency of jointly provided water and wastewater services. Utilities Policy, 24, 70–77. https://doi.org/10.1016/J.JUP.2012.09.002

Du, J., Chen, Y., & Huang, Y. (2018). A Modified Malmquist-Luenberger Productivity Index: Assessing Environmental Productivity Performance in China. European Journal of Operational Research, 269(1), 171–187. https://doi.org/10.1016/j.ejor.2017.01.006

Du, J., Liang, L., Chen, Y., Cook, W. D., & Zhu, J. (2011). A bargaining game model for measuring performance of two-stage network structures. European Journal of Operational Research, 210(2), 390–397. https://doi.org/10.1016/J.EJOR.2010.08.025

Egilmez, G., & Stewart, S. (2019). Food security performance assessment of the US states: A DEA-based Malmquist productivity index approach. International Journal of Agricultural Resources, Governance and Ecology, 15(1), 1–26. https://doi.org/10.1504/IJARGE.2019.099797

Ertay, T., Ruan, D., & Tuzkaya, U. R. (2006). Integrating data envelopment analysis and analytic hierarchy for the facility layout design in manufacturing systems. Information Sciences, 176(3), 237–262. https://doi.org/10.1016/J.INS.2004.12.001

Fang, L., & Zhang, C.-Q. (2008). Resource allocation based on the DEA model. Journal of the Operational Research Society, 59(8), 1136–1141. https://doi.org/10.1057/palgrave.jors.2602435

Färe, R., & Grosskopf, S. (2000). Network DEA. Socio-Economic Planning Sciences, 34(1), 35–49. https://doi.org/10.1016/S0038-0121(99)00012-9

Harrison, J. (2010). Data envelopment analysis (DEA): A method for measuring efficiency, benchmarking and continuous improvement. 10th Annual Effective Management Accountant Conference.

Hsieh, L.-F., & Lin, L.-H. (2010). A performance evaluation model for international tourist hotels in Taiwan—An application of the relational network DEA. International Journal of Hospitality Management, 29(1), 14–24. https://doi.org/10.1016/J.IJHM.2009.04.004

Huang, C. W., Chiu, Y. H., Fang, W. T., & Shen, N. (2014). Assessing the performance of Taiwan's environmental protection system with a non-radial network DEA approach. Energy Policy, 74(C), 547–556. https://doi.org/10.1016/j.enpol.2014.06.023

Jain, S., Triantis, K. P., & Liu, S. (2011). Manufacturing performance measurement and target setting: A data envelopment analysis approach. European Journal of Operational Research, 214(3), 616–626. https://doi.org/10.1016/j.ejor.2011.05.028

Jain, V., Sangaiah, A. K., Sakhuja, S., Thoduka, N., & Aggarwal, R. (2018). Supplier selection using fuzzy AHP and TOPSIS: a case study in the Indian automotive industry. Neural Computing and Applications, 29(7), 555–564. https://doi.org/10.1007/s00521-016-2533-z

Ji, Yong-bae, C. L. (2010). Data Envelopment Analysis. The Stata Journal, 10(2), 267–280. https://doi.org/10.1007/978-0-387-45283-8

Kao, C. (2014). Network data envelopment analysis: A review. European Journal of Operational Research, 239(1), 1–16. https://doi.org/10.1016/j.ejor.2014.02.039

Kao, C., & Hwang, S.-N. (2008). Efficiency decomposition in two-stage data envelopment analysis: An application to non-life insurance companies in Taiwan. European Journal of Operational Research, 185(1), 418–429. https://doi.org/10.1016/J.EJOR.2006.11.041

Kao, C., & Hwang, S.-N. (2010). Efficiency measurement for network systems: IT impact on firm performance. Decision Support Systems, 48(3), 437–446. https://doi.org/10.1016/J.DSS.2009.06.002

Kotler, P., & Turner, R. E. (1979). Marketing management: analysis, planning, and control. Prentice-Hall Englewood Cliffs, NJ.

Koulinas, G. K., Marhavilas, P. K., Demesouka, O. E., Vavatsikos, A. P., & Koulouriotis, D. E. (2019). Risk analysis and assessment in the worksites using the fuzzy-analytical hierarchy process and a quantitative technique – A case study for the Greek construction sector. Safety Science, 112, 96–104. https://doi.org/10.1016/j.ssci.2018.10.017

Lewis, L. F., & Sexton, T. R. (2004). Network DEA: Efficiency analysis of organizations with complex internal structure. Computers and Operations Research, 31(9), 1365–1410. https://doi.org/10.1016/S0305-0548(03)00095-9

Li, H., Chen, C., Cook, W. D., Zhang, J., & Zhu, J. (2018). Two-stage network DEA: Who is the leader? Omega (United Kingdom), 74, 15–19. https://doi.org/10.1016/j.omega.2016.12.00

Liang, L., Yang, F., Cook, W. D., & Zhu, J. (2006). DEA models for supply chain efficiency evaluation. Annals of Operations Research, 145(1), 35–49. https://doi.org/10.1007/s10479-006-0026-

Liu, C. C., Wang, T. Y., & Yu, G. Z. (2019). Using AHP, DEA and MPI for governmental research institution performance evaluation. Applied Economics, 51(10), 983–994. https://doi.org/10.1080/00036846.2018.1524131

Malmquist, S. (1953). Index numbers and indifference surfaces. Trabajos de Estadistica y de Investigacion Operativa, 4(2), 209–242.

Muhamad Arifpin, M., LH, S., & Hazami, C. H. (2012). Maintenance Performance of Malaysia's Automotive Sector: A Case Study.

Neely, A., Gregory, M., & Platts, K. (1995). Performance measurement system design. International Journal of Operations & Production Management, 15(4), 80–116. https://doi.org/10.1108/01443579510083622

Park, K. S., & Park, K. (2009). Measurement of multiperiod aggregative efficiency. European Journal of Operational Research, 193(2), 567–580. https://doi.org/10.1016/J.EJOR.2007.11.028

Park, J. Lo, Yoo, S. K., Kim, J. H., Kim, J. J., & Lee, J. S. (2015). Comparing the efficiency and productivity of construction firms in China, Japan, and Korea using DEA and DEA-based malmquist. Journal of Asian Architecture and Building Engineering, 14(1), 57–64. https://doi.org/10.3130/jaabe.14.57

Podgórski, D. (2015). Measuring operational performance of OSH management system - A demonstration of AHP-based selection of leading key performance indicators. Safety Science, 73, 146–166. https://doi.org/10.1016/j.ssci.2014.11.018

Rogge, N., & De Jaeger, S. (2012). Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model. Waste Management, 32(10), 1968–1978. https://doi.org/10.1016/J.WASMAN.2012.05.021

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. European Journal of Operational Research, 48(1), 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Simar, L., & W. Wilson, P. (2019). Central limit theorems and inference for sources of productivity change measured by nonparametric Malmquist indices. European Journal of Operational Research, 277(2), 756–769. https://doi.org/10.1016/j.ejor.2019.02.040

Stolzer, A. J., Friend, M. A., Truong, D., Tuccio, W. A., & Aguiar, M. (2018). Measuring and evaluating safety management system effectiveness using Data Envelopment Analysis. Safety Science, 104, 55–69. https://doi.org/10.1016/j.ssci.2017.12.037

Tanveer, M., & Mahbub, A. (2019). The Use of Performance Measurement in Universities of Pakistan.

Tone, K. (2005). Malmquist Productivity Index. In Handbook on Data Envelopment Analysis (pp. 203–227). https://doi.org/10.1007/1-4020-7798-x_8

Tone, K., & Sahoo, B. K. (2003). Scale, indivisibilities and production function in data envelopment analysis. International Journal of Production Economics, 84(2), 165–192. https://doi.org/10.1016/S0925-5273(02)00412-7

Triantis, K., Sarangi, S., & Kuchta, D. (2003). Fuzzy pair-wise dominance and fuzzy indices: An evaluation of productive performance. European Journal of Operational Research, 144(2), 412–428. https://doi.org/10.1016/S0377-2217(02)00141-8

Ulucan, A., Atici, K. B., & Ozkan, A. (2018). Benchmarking in higher education using data envelopment analysis and the Bologna process data. Croatian Operational Research Review, 9(2), 301–316. https://doi.org/10.17535/crorr.2018.0024

Upadhaya, B., Blount, Y., & Munir, R. (2014). Association between performance measurement systems and organisational effectiveness. International Journal of Operations & Production Management, 34(7), 853–875. https://doi.org/10.1108/IJOPM-02-2013-0091

Wang, C. H., Gopal, R. D., & Zionts, S. (1997). Use of Data Envelopment Analysis in assessing Information Technology impact on firm performance. Annals of Operations Research, 73(0), 191–213. https://doi.org/10.1023/A:1018977111455

Zainal, N., Mansor, M. A., & Saffe, S. N. M. (n.d.). Development of A Network DEA Model To Measure Production Line's Performance: A Conceptual Paper.

Zeydan, M., & Çolpan, C. (2009). A new decision support system for performance measurement using combined fuzzy TOPSIS/DEA approach. International Journal of Production Research, 47(15), 4327–4349. https://doi.org/10.1080/00207540802662870

Zhou, Z., Sun, L., Yang, W., Liu, W., & Ma, C. (2013). A bargaining game model for efficiency decomposition in the centralized model of two-stage systems. Computers & Industrial Engineering, 64(1), 103–108. https://doi.org/10.1016/J.CIE.2012.09.014